"On the Electrical Resistivity of Pure Mercury at the Temperature of Liquid Air." By JAMES DEWAR, LL.D., F.R.S., Fullerian Professor of Chemistry in the Royal Institution, and J. A. FLEMING, M.A., D.Sc., F.R.S., Professor of Electrical Engineering in University College, London. Received May 19,—Read June 4, 1896.

Although the electrical resistivity of mercury at ordinary temperatures has been carefully examined by many observers, and accurate determinations made of the specific resistance* and temperature coefficient, and in addition an examination made of the variation of resistivity in mercury when cooled to temperatures as low as $-100°$ C.,† we considered it would be of interest to examine the behaviour of pure mercury in respect of change in electrical resistivity when cooled to the temperature obtained by the employment of boiling liquid air. With this object we prepared a sample of very pure mercury in the following manner: Ordinary distilled mercury was shaken up with nitric acid in the usual manner to free it from other metals, and then carefully dried. It was then introduced into a bent glass tube formed of hard glass. This bent tube had both ends sealed, and a side tube connected in at the bend, by which it could be connected to a mercury vacuum pump. Two or three hundred grammes of the mercury was then introduced into one bend, and a high vacuum made in the tube. The side tube was then sealed off from the pump, and the mercury distilled over from one leg into the other. For this purpose, one leg of the bent tube was placed in ice and salt, and the other submitted to a gentle heat just sufficient to make the mercury distil under reduced pressure without ever bringing it into active ebullition. In this way the mercury is distilled over at a very low temperature, and the portion condensing in the cooler limb of the bent tube is entirely free from any contamination with silver, lead, zinc, or tin. By performing this distillation two or three times successively on the same mercury, a small quantity of mercury is at last obtained in an exceedingly pure condition. A glass spiral tube was then formed of lead glass, consisting of a tube having an internal diameter of about 2 mm., and a length of about 1 metre. This tube was bent into a spiral of about twelve close turns, each turn being nearly 2·5 cm. in diameter, and the ends of this spiral provided with enlarged glass ends formed of wider tube. The spiral,

* "The Specific Resistance of Mercury," by Lord Rayleigh and Mrs. Sidgwick (*Phil. Trans. R. S.*, Part I, 1883). See, also, Mr. R. T. Glazebrook (*Phil. Mag.*, Oct., 1885), for other values.

† Cailletet and Bouty (*Compt. Rend.*, **100**, 1188, 1885).

after being cleaned, was then very carefully filled with the purified mercury, and by running the mercury through a spiral several times, all air bubbles and air film were finally removed. Into the wider ends of the spiral, amalgamated copper electrodes were introduced, consisting of copper wire 4·4 mm. in diameter; the wider terminal ends of the spiral were then closed by paraffined corks to keep the copper electrodes in position. This spiral, full of mercury, was placed in a test-tube, and paraffin wax cast round it so as to enclose it entirely, leaving only the copper electrodes protruding. In order to determine the temperature of the mercury in the glass spiral tube, a platinum wire, the resistance of which was known at all temperatures down to the temperature of liquid air, was also embedded in the paraffin wax closely in contact with the glass spiral, and proper electrodes brought out to enable the resistance of this platinum wire to be determined. This mass of paraffin wax was then cooled down in a vacuum vessel kept filled up with liquid air until the whole mass reached the temperature of the liquid air. The glass spiral and thermometer enclosed in wax was then removed from the bath of liquid air and placed in a vacuum-jacketed test-tube, in order that it might warm up with extreme slowness to the ordinary temperature of the air.

Having in this manner cooled the mass of paraffin enclosing the glass spiral filled with mercury and the platinum resistance wire entirely to the temperature of liquid air, a series of observations were taken with the aid of two observers, one measuring the resistance of the mercury by a Wheatstone's Bridge, while at the same time the other observer at another slide wire bridge measured the resistance of the platinum wire, these observations being taken quite simultaneously, and continued whilst the mass heated up from $-197{\cdot}9^\circ$ (platinum temperature) to 0°. All proper corrections were then applied to correct for the resistance of the connecting wires and the bridge temperature; and the observed resistance of the platinum wire employed was corrected to determine from its resistance temperatures in terms of the standard platinum thermometer employed by us in our investigations on the thermo-electric power of metals and alloys (see Dewar and Fleming, 'Phil. Mag.,' July, 1895, p. 95). This standard thermometer has always been denoted by the letter P_1. The following table shows the corrected resistance of the mercury column and the corresponding platinum temperatures, as also the specific resistance of the mercury calculated from the accepted resistivity at 0° C. :—

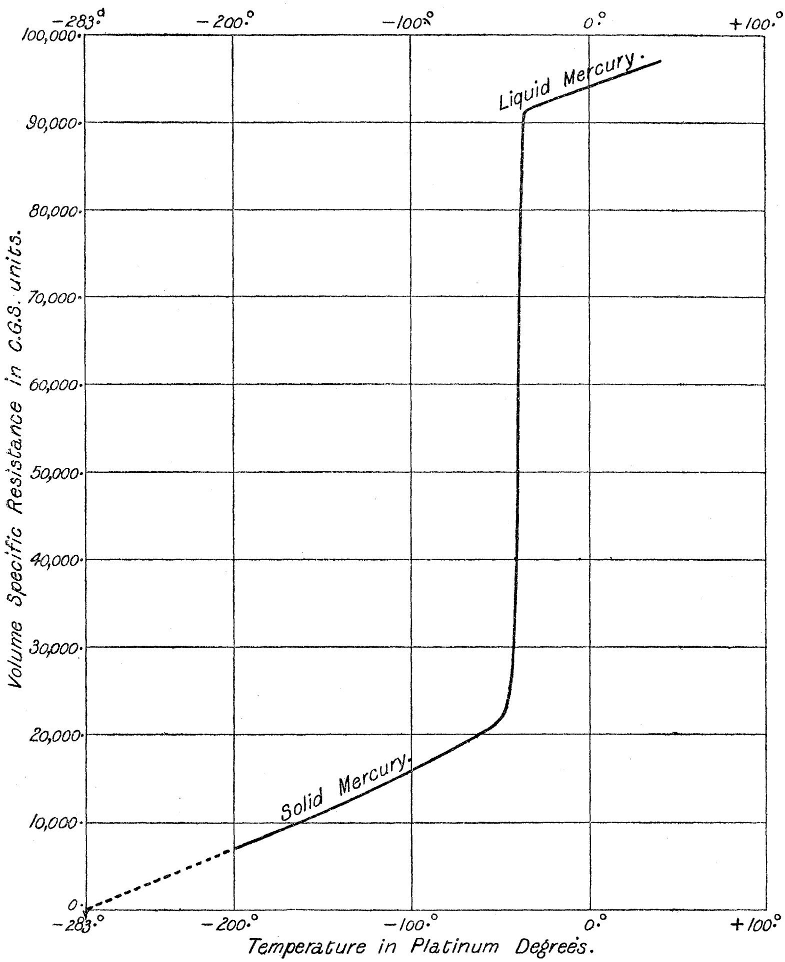
Resistivity of Pure Mercury in C.G.S. Units at various Temperatures in Platinum degrees.

Platinum temperature, *pt*, in terms of the standard platinum thermometer P_1.	Observed and corrected resistance of mercury in lead glass spiral in ohms.	Resistivity of mercury in glass in C.G.S. units.
−197·9	0·0551	6970
−197·8	0·0551	6970
−197·5	0·0551	6970
−196·9	0·0566	7160
−195·2	0·0581	7350
−191·2	0·0601	7600
−182·7	0·0641	8100
−173·2	0·0721	9120
−168·4	0·0761	9620
−165·1	0·0781	9870
−157·4	0·0836	10570
−149·7	0·0886	11200
−143·0	0·0931	11770
−131·9	0·1011	12780
−128·3	0·1041	13160
−122·9	0·1081	13670
−117·5	0·1121	14170
−108·4	0·1191	15060
−103·7	0·1231	15560
− 97·0	0·1281	16200
− 91·1	0·1331	16830
− 85·0	0·1381	17460
− 79·1	0·1432	18100
− 73·1	0·1482	18740
− 67·4	0·1532	19370
− 63·2	0·1582	20000
− 57·6	0·1632	20630
− 52·5	0·1682	21270
− 48·9	0·1753	22160
− 47·0	0·1833	23180
− 46·0	0·1883	23810
− 44·9	0·1933	24440
− 44·2	0·1983	25070
− 43·5	0·2033	25700
− 43·0	0·2183	27600
− 42·4	0·2283	28860
− 42·1	0·2383	30130
− 41·9	0·2484	31410
− 41·2	0·2584	32670
− 40·8	0·2784	35200
− 40·6	0·2884	36460
− 40·4	0·3184	40260
− 39·7	0·3585	45330
− 39·5	0·3885	49120
− 39·4	0·4185	52920
− 39·3	0·4385	55440
− 39·1	0·4785	60800
− 38·7	0·5186	65570
− 38·5	0·5486	69360
− 38·3	0·5786	73160
− 37·7	0·6086	76950

Platinum temperature, *pt*, in terms of the standard platinum thermometer P_1.	Observed and corrected resistance of mercury in lead glass spiral in ohms.	Resistivity of mercury in glass in C.G.S. units.
− 37·6	0·6387	80760
− 37·2	0·6587	83280
− 36·7	0·6787	85810
− 36·0	0·7087	89600
− 35·2	0·7208	91140
− 33·7	0·7228	91380
− 31·2	0·7248	91640
0	0·7440	94070
+ 13·1	0·7518	95060
+ 16·3	0·7540	95330
+ 35·4	0·7653	96760

Adopting the value for the specific resistance of pure mercury at 0° C., which has been recommended by the Board of Trade Electrical Committee, viz., 94,070 C.G.S. units, we have reduced the observed resistances of the mercury column at various temperatures to their equivalents in resistivity in absolute units, and placed these numbers against the observed resistances in the table above. As the specific resistance of mercury has been so carefully observed by many observers, we did not, for a moment, consider it necessary to attempt a further determination of this constant. On plotting out these values of the resistivity of mercury in the form of a curve in terms of the corresponding platinum temperatures, we find the resistivity curve has the form shown in fig. 1. It will be noticed that the resistivity of the mercury decreases gradually from the point at which the observations finished, viz., at +35° C., to the temperature −36° on the platinum scale. At this point the resistivity rapidly decreases to about one-quarter of its value in falling from −36° to −50°, and this sudden change all takes place within the range of about 14° of temperature. At the temperature of −50° on the platinum scale the resistivity curve again changes direction, and continues downwards in such a direction as to show that if produced along the same line from the lowest temperature actually observed, viz., −204° on the platinum scale, it would pass exactly through the absolue zero of temperature on this scale, which is −283° *pt*. It is also interesting to note that the part of the curve which corresponds to the mercury in the liquid state is almost exactly parallel to that part of the curve which corresponds to mercury in the solid condition, although, owing to the difference in the absolute values of the resistivities at these parts, the temperature coefficients as usually defined are very different. In the solid condition between the temperatures of −197·9° and −97°, the mean increase in resistivity is

FIG. 1.



93·14 C.G.S. units per degree rise of temperature on the platinum scale; between $-108·4°$ and $-57·6°$ the mean increase in resistivity in C.G.S. units per degree is 109·6; in the liquid condition between the temperature $-35·2°$ and 0° the mean increase in resistivity in C.G.S. units per degree is 83·2; temperature measurement being on the platinum scale as above defined. It may be stated here that temperatures defined by this platinum scale do not differ by more than about 0·5° from the Centigrade scale down to temperatures of $-100°$, but that the temperature of boiling liquid oxygen which, on the Centigrade scale is denoted by $-182°$, is, on the platinum scale

derived from our standard thermometer, denoted by $-196{\cdot}7^\circ$. This would show, therefore, that the temperature coefficient as usually defined is 0·000884 between -35° and 0°.*

These observations are specially interesting as giving additional proof that in the case of a metal of known purity the variation of resistivity, as the metal is continuously cooled, is such as to indicate that it would in all probability vanish at the absolute zero of temperature. In the case of mercury, we are able to obtain a metal in a state of almost perfect chemical purity, and which, when continuously cooled, passes into the solid condition under circumstances which are entirely favourable to the prevention of stresses in the interior of the metal, due to cooling. These measurements, therefore, afford a further confirmation of the law which we have enunciated as a deduction from experimental observations, that the electrical resistivity of a pure metal vanishes at the absolute zero of temperature.

"On the Magnetic Permeability and Hysteresis of Iron at Low Temperatures." By J. A. FLEMING, M.A., D.Sc., F.R.S., Professor of Electrical Engineering in University College, London, and JAMES DEWAR, LL.D., F.R.S., Fullerian Professor of Chemistry in the Royal Institution, &c. Received May 27,—Read June 11, 1896.

Although considerable attention has been paid to the changes produced in the magnetic properties of iron, particularly its magnetic permeability and hysteresis, at ordinary and at higher temperatures, but little information has been obtained up to the present on the behaviour of iron and steel as regards magnetic properties when cooled to very low temperatures. By the employment of large quantities of liquid air we have been able to conduct a long series of experiments on this subject, the results of which we propose here briefly to summarise, leaving for a future communication fuller details and discussion of the results. The experimental work has consisted in making measurements, chiefly by ballistic galvanometer methods, of the permeability and hysteresis loss in certain samples of iron and steel, taken in the form of rings or cylinders. The first experiments were concerned with the variation of the magnetic permeability of soft iron under varying magnetic forces, the iron being kept at a constant low temperature, obtained by placing it in liquid air in a state of very quiet ebullition in a vacuum vessel.

* This is in close agreement with the values obtained by Guillaume, Mascart, and Strecker for temperatures between 0° C. and +30° C.